Integrated Antenna Design for Passive X-band RFID Transponder

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Abstract: Fully integrated passive RFID tag is the ideal solution to dramatically reduce the costs and sizes of RFID tags. In order to achieve this goal, three basic requirements are necessary: high gain on-chip antenna, high efficiency RF-DC converter and ultra-low power mixed signal circuitry. This paper proposes an asymmetric dipole antenna as the candidate for the on-chip antenna of the fully integrated RFID tags. The proposed antenna has been compared with the standard patch antenna and the symmetric dipole antenna with balun. All antennas in this paper have been investigated by using Sonnet EM solver with the same substrate stack. Simulation results of the prototype antenna demonstrate an over 4dB higher gain than that of the patch antenna at 10GHz and 10 dB higher than symmetric dipole antenna with similar size. Therefore the asymmetric dipole antenna shows as a promising candidate for ultra-low cost and miniature RFID tags.

Keywords: On-chip antenna, X-band, RFID tags

1. Introduction

Radio-Frequency identification (RFID) is an emerging technology due to its advantages compared to conventional bar-code system [1-3]. Some of its advantages are the ability for longer reading/writing distance, more advanced data management, faster processing speed, and reliable operation in difficult environments[4]. RFID systems are increasingly used in the different areas, such as supply chain, price tags, credit cards, subway passes, and automobile toll collection[5].

Out of three types of RFID tags (active, passive and semi-passive), passive tags attract broad interests due to its low cost and long life time. Passive tags utilize antennas to harvest RF energy for all their operations, so the antenna design for passive tags are critical for their performance[6]. The type of antenna used by RFID tags is closely related to the target applications. For example, patch antennas are well suited for metallic objects since it is possible to make use of their bodies as a ground plane [7-8].

The integration of the antenna with the RFID tag is the final hurdle to achieve a fully integrated single-chip wireless system with largely reduced cost and form factor. Low radiation efficiency is the main problem of the previous studies involved in developing on-chip antennas [9]. In this paper, we propose an on-chip antenna structure operating in the X-band frequency and compare it with the existing antenna designs. The proposed antenna, a patch antenna and a symmetric dipole antenna with balun were designed, simulated and optimized in Sonnet software.

2. Proposed On-chip Antenna Design

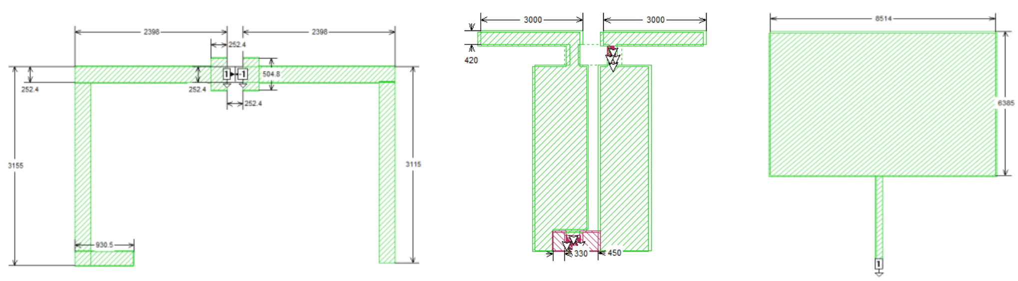
The layout of the proposed antenna is shown in Fig.1 (a) with differential port. It is an asymmetric dipole antenna. Its overall electrical length from the feed point to end of the long section is about a quarter wavelength ($\lambda_0/4$) at the resonance frequency of operation. The final electrical dimensions of the antenna are $0.17\lambda_0$ by $0.1\lambda_0$. Throughout the antenna design process, asymmetric dipole antenna exhibits superior performance over symmetric dipole and patch antennas. The IBM 0.18µm six-metal layer CMOS process is used for electromagnetic analysis of the antennas. The dielectric stack starts with 700µm silicon with a loss tangent of 0.004, and conductivity of 7.41S/m. The conductive layer is defined as 5µm thick aluminum film. The complete IBM PDK 0.18µm dielectric stack is given in Table 1.

Table 1: Substrate stack description for Sonnet simulation

Thickness (µm)	Mat. Name	Erel	Dielectric Loss tangent	Diel Cond. (S/m)
10000.0	Air	1.0	0.0	0.0
4.3	AM	3.8	0.0	0.0
4.0	SiO_2	4.1	0.0	0.0
6.7	SiO_2	4.1	0.0	0.0
700.0	Silicon	11.9	0.004	7.41

Symmetric dipole antenna mentioned [10] in Fig. 1(b) consists of a via-hole balun acts as an unbalanced to balanced transformer between the feed coaxial line and the two printed dipole strips. The structure is resized to fit 10GHz application. The length of the dipole strips is approximately 1/4 of the wavelength. The ground plane and the of the microstrip line and the dipole strips are in the same plane. The widths of the dipole arm strips are chosen to be approximately one-tenth of the wavelength.

The patch antenna in Fig. 1(c) is designed so that one side is half wavelength. When building it on a substrate it can be fed through a microstrip line.

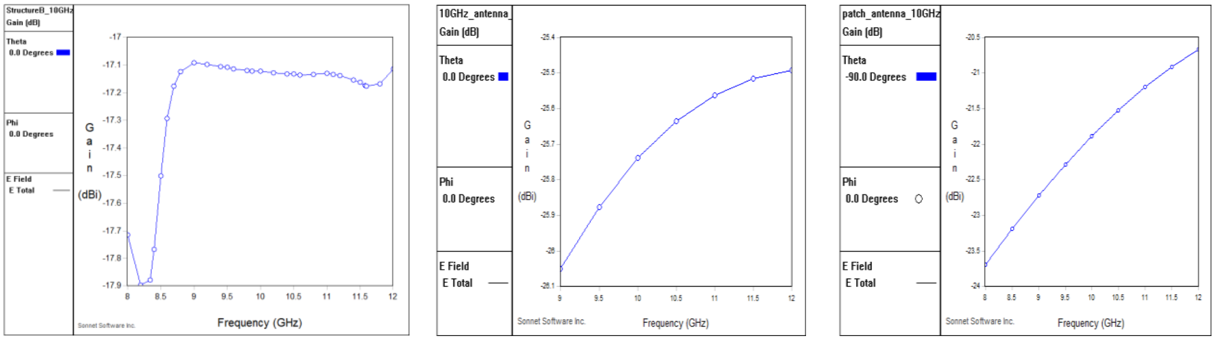


(a) (b) (c)

Fig.1 Antenna layouts for (a) asymmetric dipole antenna with differential port, (b), Symmetric dipole antenna with balun, and (c) patch antenna.

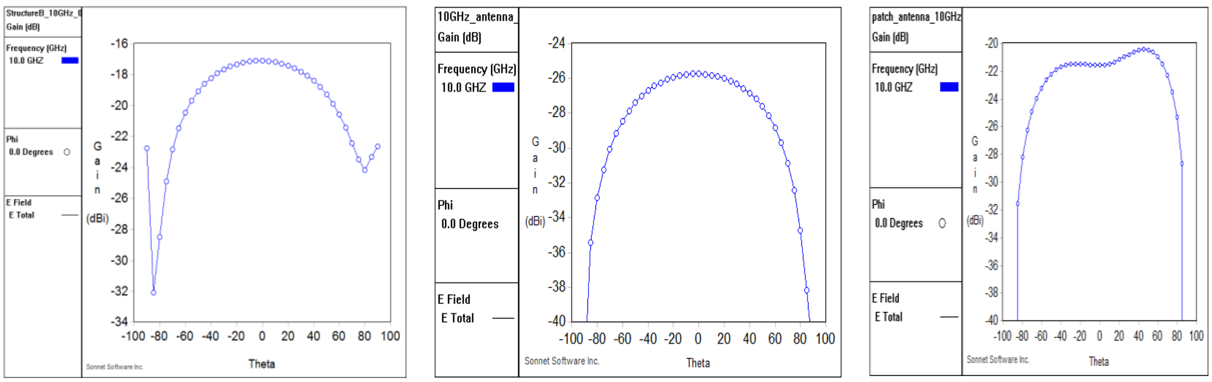
3. Simulation Results

The simulated antenna gains vs. frequency are shown in Fig.2. The proposed antenna with differential port (Fig.2 (a)) has a gain of -17.1dBi. In contrast, symmetric dipole antenna with balun in the same dielectric environment shows a modest gain of -25.7dBi and the Patch antenna has a gain of -21.5dBi. The gain vs. theta of the proposed antenna was compared with the symmetric dipole antenna with balun and the patch antenna (Fig. 3).



(a) (b) (c)

Fig.2 Directive gain at (φ=θ=0) vs. frequency of (a) asymmetric dipole antenna differential port, (b) Symmetric dipole antenna, and (c) patch antenna.



(a) (b) (c)

Fig.3 Antenna pattern plots of gain (φ=θ=0) vs. theta of (a) asymmetric dipole antenna differential port, (b) Symmetric dipole antenna, and (c) patch antenna.

Table 2: Layout dimension and gain comparison

Antenna Type	Gain (dBi)	f_r (GHz)	Maximum Linear Dimension (μm)
Asymmetric Dipole Antenna differential Port	-17.1	10.2	5048
RFIC on-chip dipole antenna	-25.7	10.0	6600
Patch Antenna	-21.5	10.0	8514

Table 2 shows the comparison of the proposed antenna with the symmetric dipole antenna with balun and patch antenna. The asymmetric dipole antenna with differential port has the highest gain of -17.12dBi with similar maximum linear dimension to the other two structures. To compare with other state-of-the-art small antennas, the next step will be fabricating and measuring the proposed antenna structure in IBM 0.18 CMOS technology.

4. Conclusion

An asymmetric dipole on-chip antenna with electrical dimensions of $0.17\lambda_0$ by $0.10\lambda_0$ is presented in this paper with gain of -17.1dBi in X-band frequency. The proposed antenna provides a significant higher gain than the patch antenna and symmetric dipole antenna with balun. Therefore the asymmetric dipole antenna is a promising candidate of the on-chip antenna of the fully integrated passive X-band RFID transponder.

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